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Larsen et al.

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[54] **PARTIALLY TEMPERATURE COMPENSATED LOW NOISE VOLTAGE REFERENCE**

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[51] **Int. Cl.**[6] **G05F 3/16**; G05F 1/10; G05F 3/02

[52] **U.S. Cl.** **323/313**; 327/539

[58] **Field of Search** 323/313, 314, 323/316; 327/539

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[57] **ABSTRACT**

A reference voltage source has at least one transistor having a base, emitter and collector electrode operating in an active state that has an inherent voltage drop between its base and emitter electrodes to generate a low noise core voltage which is applied to the input of an amplifier to set the amplifier operating point, and thereby the amplifier output, which is the reference voltage. The reference voltage is temperature compensated by providing the amplifier with a feedback loop, or by altering the core voltage applied to the amplifier, or by altering the gain of the amplifier. Several transistors can be connected in series and their base to emitter voltage drops added to change the core voltage value.

9 Claims, 3 Drawing Sheets

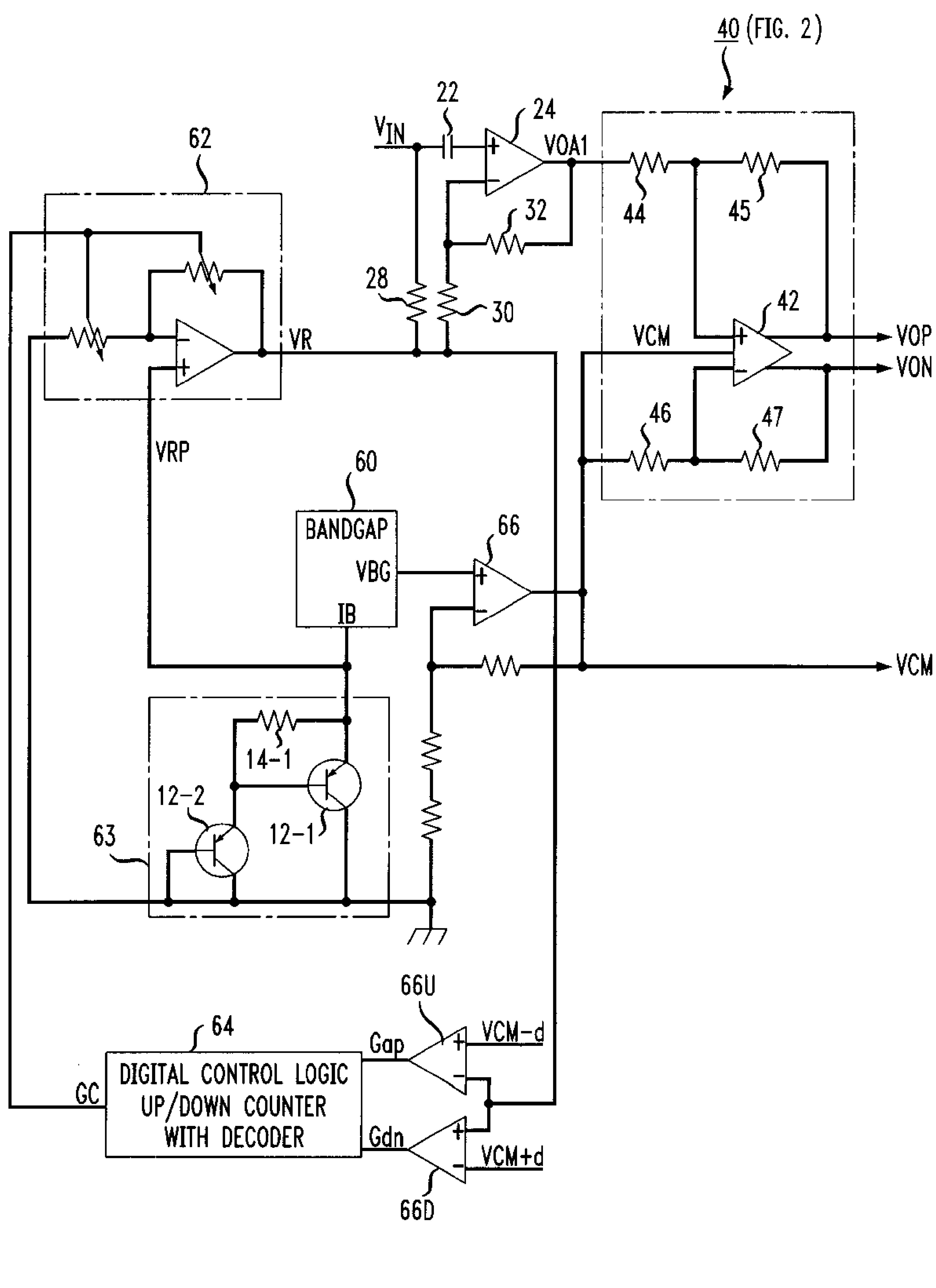
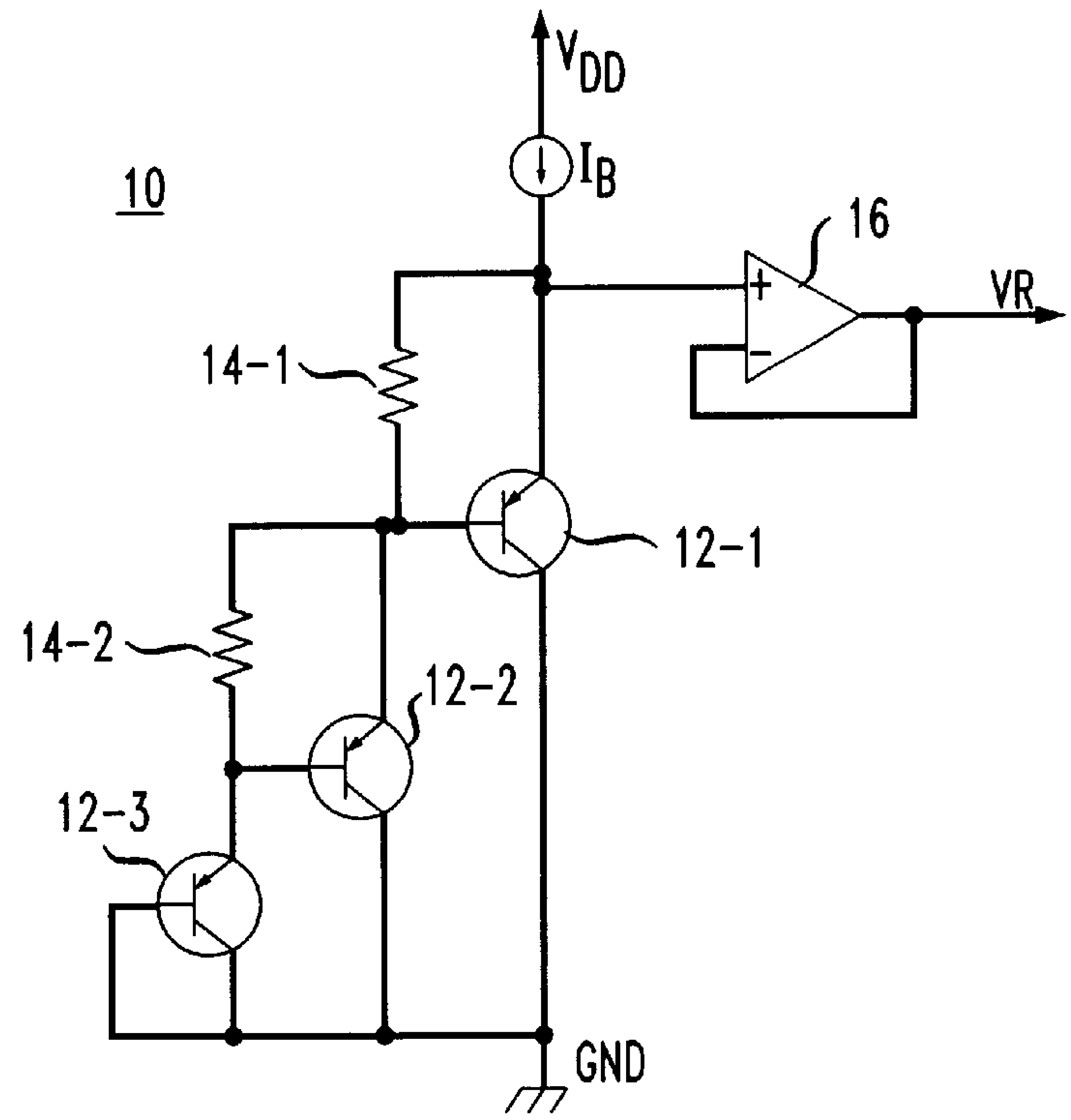
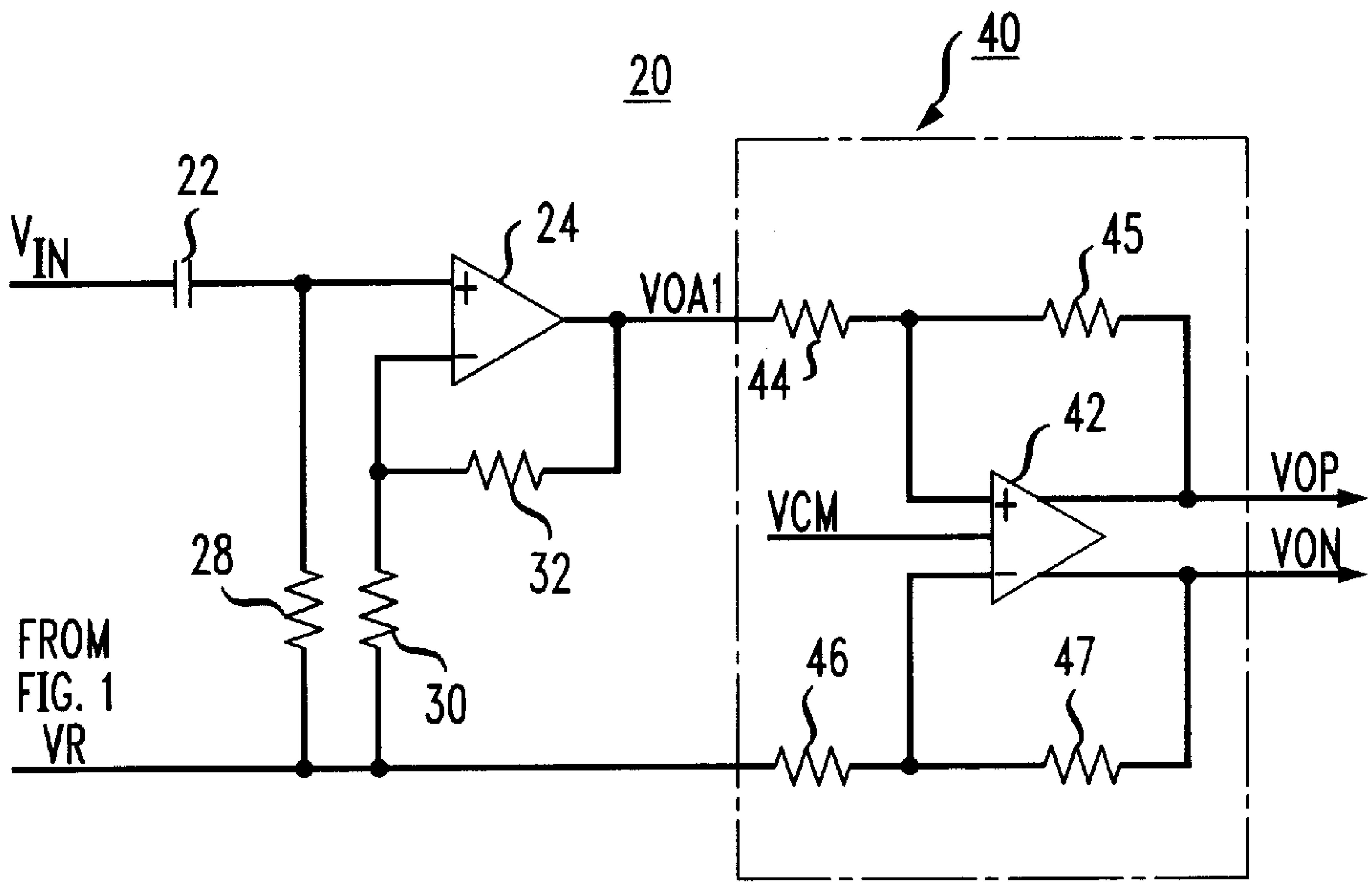


FIG. 1



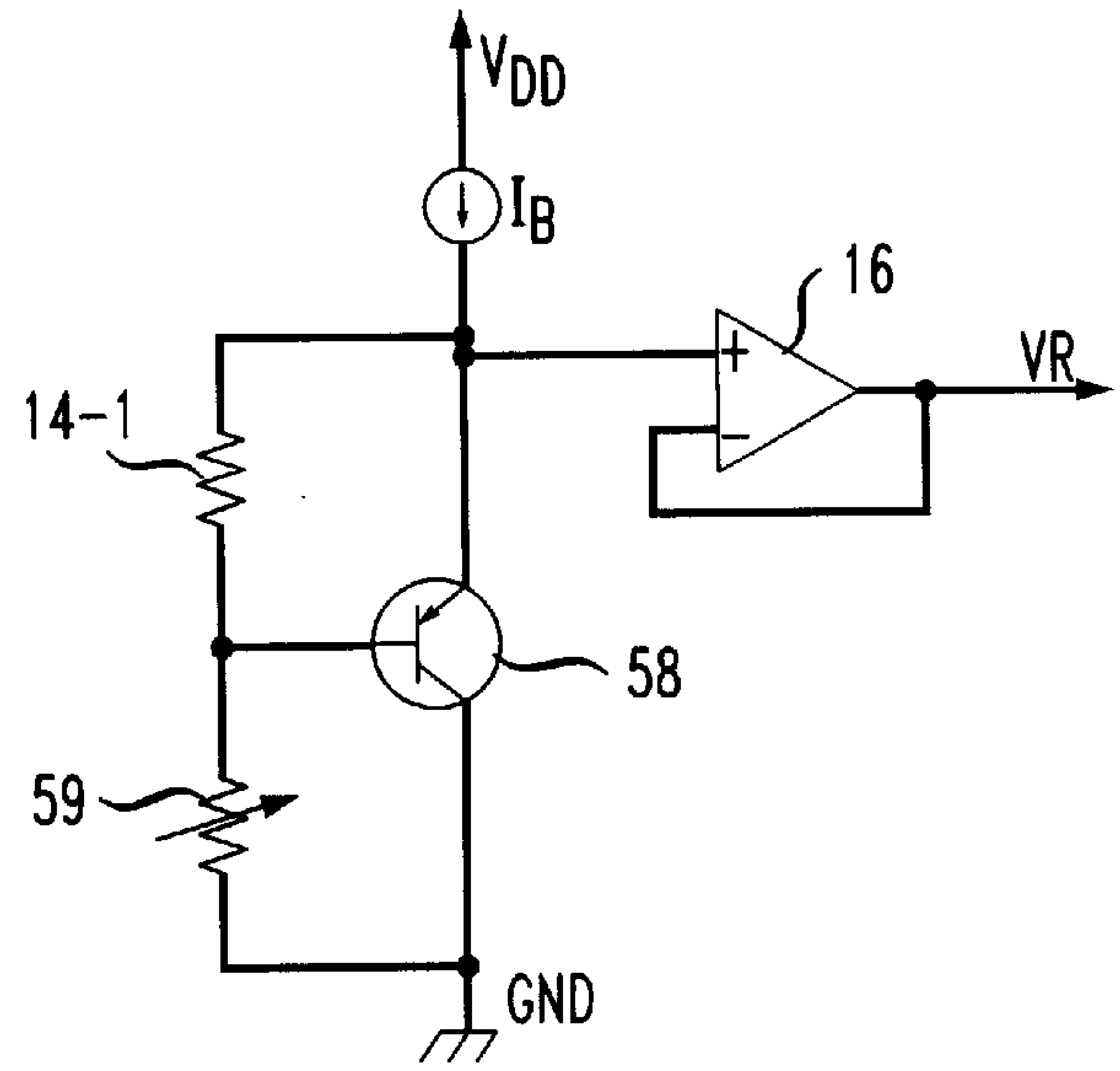
V_{DD}
I_B
10
16
VR
14-1
12-1
14-2
12-2
12-3
GND

FIG. 2



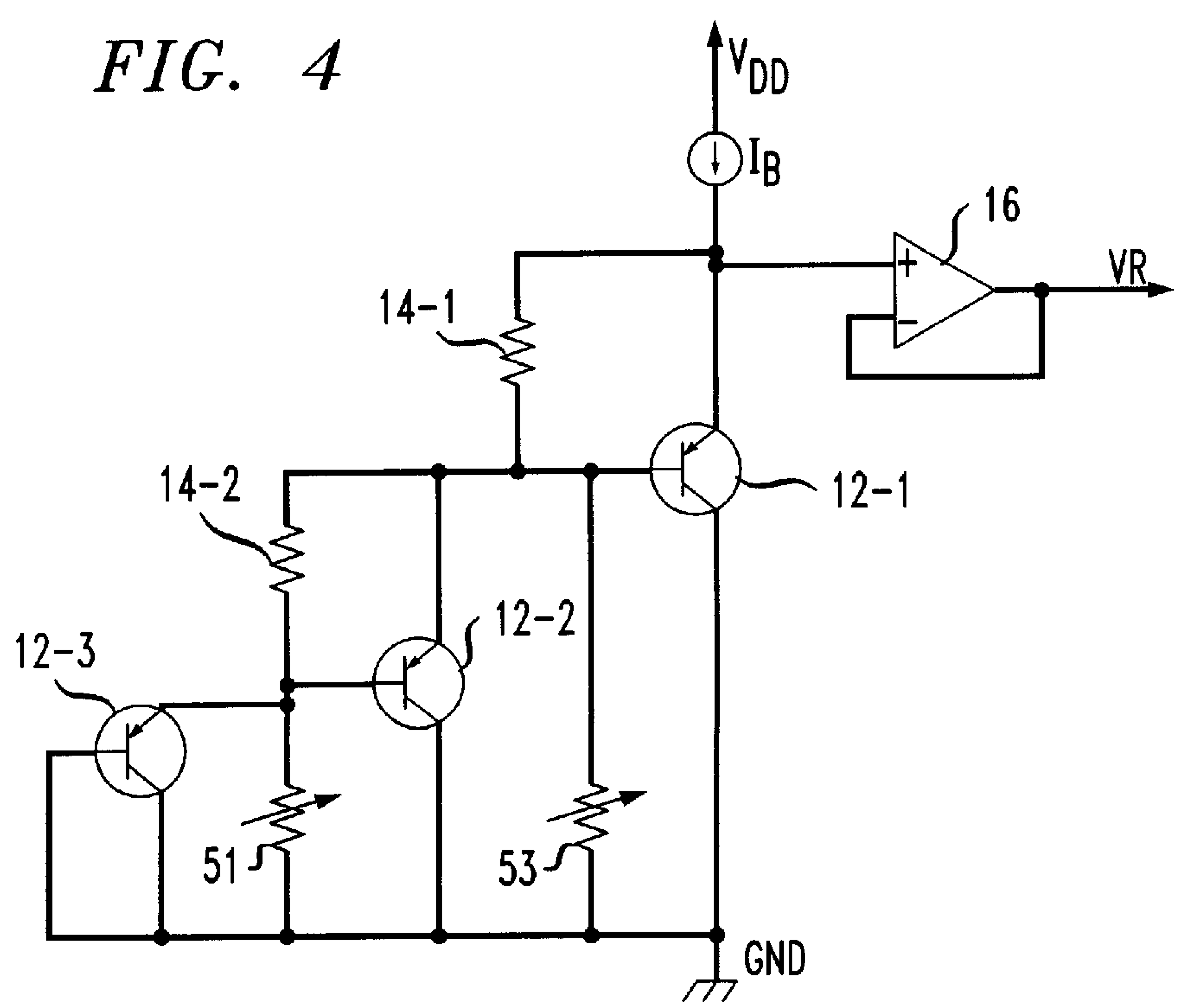
40
20
22
V_{IN}
24
VOA1
45
44
42
VCM
VOP
VON
28
32
FROM
FIG. 1
VR
30
46
47

FIG. 3



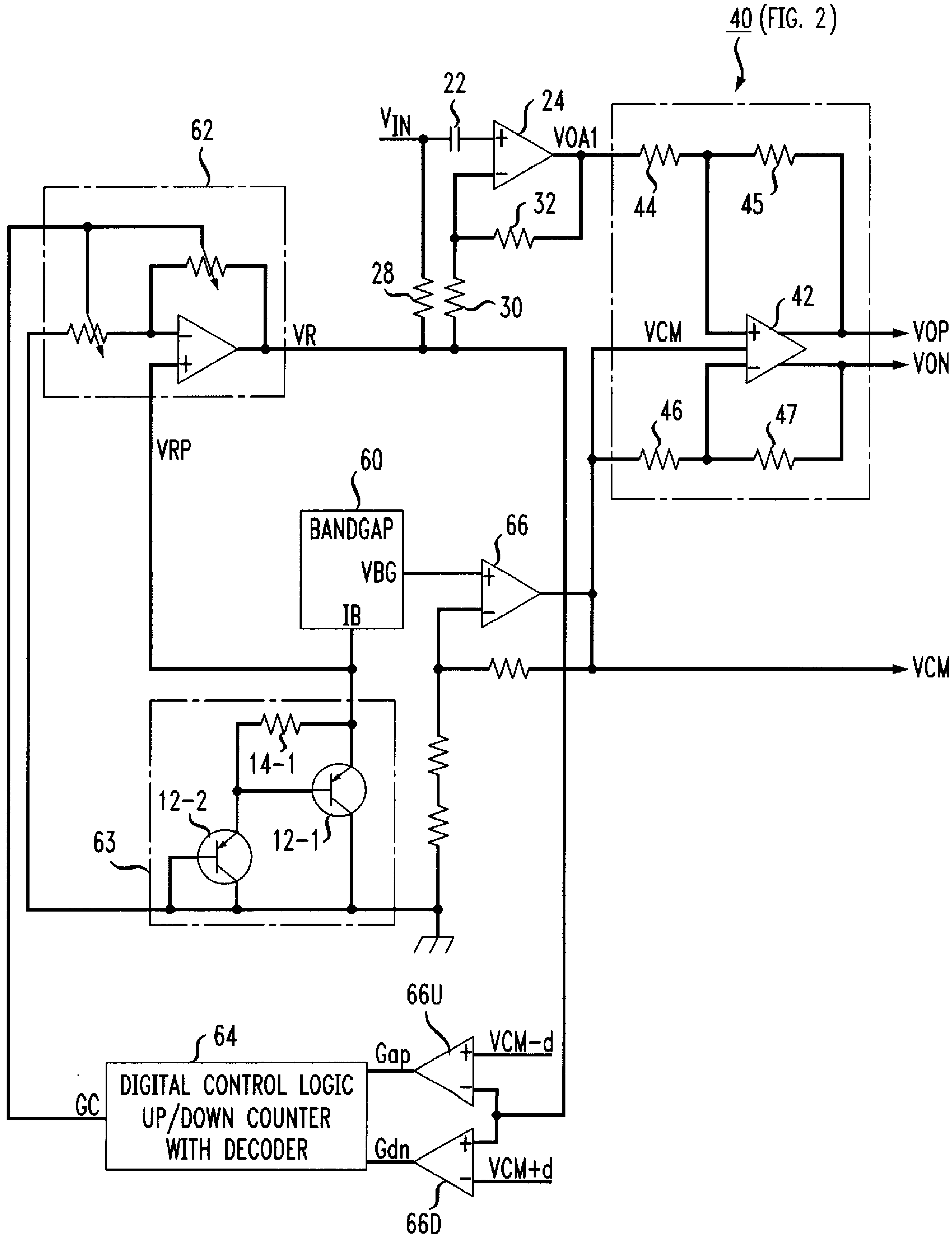
V_{DD}
I_B
16
VR
14-1
58
59
GND

FIG. 4



V_{DD}
I_B
16
VR
14-1
14-2
12-1
12-2
12-3
51
53
GND

FIG. 5


40 (FIG. 2)
22
24
VIN
VOA1
62
32
44
45
28
30
42
VR
VCM
VOP
VON
46
47
VRP
60
BANDGAP
VBG
IB
66
VCM
14-1
12-2
12-1
63
66U
64
VCM-d
Gap
DIGITAL CONTROL LOGIC
UP/DOWN COUNTER
WITH DECODER
GC
Gdn
VCM+d
66D

PARTIALLY TEMPERATURE COMPENSATED LOW NOISE VOLTAGE REFERENCE

FIELD OF THE INVENTION

The invention relates to a low noise reference voltage source that is partially temperature compensated.

BACKGROUND OF THE INVENTION

In various applications there is a need for a source of a stable reference voltage. For example, in an IC chip containing a large number of circuits, a reference voltage is used to set input reference levels for some of the circuits that receive other signals. It is preferred that the reference voltage source be made a part of the IC chip using the same fabrication technology so as to avoid the use of external components and reduce cost. Also, it is desirable to generate the reference voltage with low noise characteristics so as not to adversely affect the signals of the circuits in which it is used. Further, it is desirable for the reference voltage source to be temperature compensated to as great an extent as possible.

SUMMARY OF THE INVENTION

It is a general object of my invention to provide a low noise and stable reference voltage for an IC chip. It is a further object of my invention to provide temperature compensation for the reference voltage source.

In accordance with my invention, an IC chip is fabricated with one or more transistors. The inherent base emitter voltage drop of an active (conducting) transistor establishes a low noise core voltage and the drops of several such transistors can be added in series to increase the core voltage value. The core voltage is applied to the input of an amplifier and is amplified to produce a somewhat noisier, but still relatively low noise, output reference voltage to be used for other circuits. The reference voltage is temperature compensated by providing the amplifier with a feedback loop, or by altering the core voltage applied to the amplifier, or by altering the gain of the amplifier.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects and advantages of my present invention will become more apparent upon reference to the following detailed description and the annexed drawings in which:

FIG. **1** is a schematic diagram of one illustrative embodiment of my invention of a low noise core voltage generator;

FIG. **2** is a schematic diagram of a balanced converter utilizing the low noise reference voltage generator;

FIG. **3** is a schematic diagram of an illustrative embodiment of my invention providing temperature compensation to adjust the low noise core voltage;

FIG. **4** is a diagram of a further illustrative embodiment which is a modification of the circuit of FIG. **3**; and

FIG. **5** is a schematic diagram of a circuit illustrative of an embodiment of my invention for adjustment of the gain of an amplifier producing the reference voltage.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** shows a circuit **10** for producing the low noise reference voltage VR. The circuitry of the invention is preferably implemented by integrated circuit (IC) production techniques as part of an IC chip containing one or more other circuits which are to utilize the reference voltage. Generator **10** is biased by a current source IB from a voltage supply V_{DD} and is illustratively shown as having three bipolar PNP transistors **12-1**, **12-2** and **12-3** connected in series in a manner to produce the sum of the inherent base to emitter VBE voltage drops of the three transistors. That is, the emitter of transistor **12-1** receives the current source IB and its collector is connected to ground. The base of transistor **12-1** is connected to the emitter of transistor **12-2** and the base of transistor **12-2** connected to the emitter of transistor **12-3**. The collector of each of the transistors **12-2** and **12-3** is also connected to ground.

A resistor **14-1** connects the junction of the base of transistor **12-1** and the emitter of transistor **12-2** to the IB bias current. A resistor **14-2** is connected from this junction to the junction of the base of transistor **12-2** and the emitter of transistor **12-3**. That is, resistors **14-1** and **14-2** supply operating current to the transistors **12-2** and **12-3**. Separate current sources from V_{DD} could be alternately used (not shown).

Each of the transistors **12** is operated in an active state due to the voltages applied to its emitter and base and the grounding of its collector. There is an inherent voltage drop VBE produced by each transistor **12** in its active state and the VBE voltage drops of the three transistors add in series to produce a core voltage.

The sum of the VBE voltage drops of the three transistors **12** appears at the emitter of transistor **12-1** and is applied as the core voltage to the non-inverting (+) input of a conventional low noise operational amplifier **16** having the usual feedback path. Low noise resistors (not shown) could be used to add gain to this amplifier stage. The output of amplifier **16** is the reference voltage VR. This voltage has relatively low noise since the transistors **12** inherently have a low noise output when operating in an active state to produce the core voltage.

FIG. **2** shows a single-ended input to balanced output converter utilizing the voltage from the low noise reference voltage source **10** of FIG. **1**. The converter can be on the same integrated circuit chip as the reference voltage source. Here, the single-ended converter input signal VIN is supplied through a capacitor **22** to the non-inverting (+) input of an operational amplifier **24**. The input signal can be either of the analog or digital type. Bias voltage is supplied by resistors **28** and **30** to the non-inverting (+) and inverting (−) inputs of amplifier **24** from the reference voltage VR source, such as produced by circuit **10** of FIG. **1**. A resistor **32** is provided as the feedback element for amplifier **24** between its output and inverting (−) input.

Amplifier **24** has a single-ended output VOA1 that is to be converted to a fully balanced output, that is, two signals of opposite phase. To accomplish this, a converter **40** is provided. Converter **40** has an operational amplifier **42** whose non-inverting input (+) receives the amplified, single-ended, input signal VOA1 through a resistor **44** and produces opposed phase positive and negative output signals VOP and VON. The inverting input (−) of the amplifier is biased with the reference voltage VR through resistor **46**. Resistors **45** and **47** provide the feedback from the respective positive output and the negative output of the amplifier **42** back to each of the corresponding amplifier non-inverting and inverting inputs.

Any noise introduced at either of the inverting or non-inverting input nodes of amplifier **24** will be added directly to the input VIN signal. The converter amplifier **42** of FIG.

2 cannot distinguish between noise fed into node VR and a signal fed into node VOA1. However, noise added to VCM, the common mode input of amplifier **42**, will be added as a common mode output signal, and thus will be rejected by the common mode rejection of the system. The common mode is defined as the average of the inputs or outputs. Typically, the common mode of the amplifier input and output are the same, and typically this is a DC voltage which can be generated either within the amplifier or externally. It is well known that in well designed balanced amplifiers, variations and noise on the common mode terminal are highly attenuated when the outputs are viewed differentially (VOP–VON). Thus, a well regulated noisier reference can be used for the amplifier **42** to provide a well defined common mode output of the overall stage.

VR is based on the three VBE drops of the transistors **12**, and has a theoretical temperature dependency that is typically about −6 mV/C°. Thus, VR could vary as much as from 2.1 V to 1.4 V as the temperature goes from −40° C. to +85° C. By incorporating the low noise reference voltage source in a feedback loop with variable gain, the low noise reference voltage can be altered to keep it within a certain range of a fixed temperature-independent reference. This could be done by altering the reference itself, or altering the external gain.

FIG. **3** shows one possible arrangement for adjusting the reference voltage VR. The same reference numerals are used for the same components shown in FIG. **1**. Here, there is a single PNP transistor **58** whose emitter is directly connected to the bias current IB and whose base is also connected to the emitter by resistor **14-1**. A variable resistor **59** connects the base to ground. The collector of transistor **58** is also connected to ground. Resistor **59** is of the temperature sensitive type so that its resistance value varies based on the operating temperature. Adjusting the variable resistor **59** sets the conduction point of transistor **58**, which sets the voltage at the non-inverting input (+) of the operational amplifier **16**. This controls the output reference voltage VR of the amplifier.

FIG. **4** shows an alternate way to compensate for variations in the emitter-base voltage with temperature by adjusting the current through the bottom two transistors **12-2** and **12-3** of the VR generator. The circuit of FIG. **4** corresponds to that of FIG. **1** and the same reference numerals are used for the same components. Here, a variable resistor **51** is connected from the emitter of transistor **12-3** to ground and a variable resistor **53** is connected from the emitter of transistor **12-2** to ground. The resistors **51** and **53** are temperature sensitive.

By increasing the resistance value of resistor **51** as ambient temperature increases, more current will flow through the transistor **12-3** emitter-base junction, and by increasing the value of resistor **53**, more current will flow through the emitter-base junction of transistor **12-2**. Basically, the resistors **51** and **53** have temperature coefficients of a value to offset the temperature induced VBE variation of the transistors **12**.

The circuit implementation of FIG. **4** has a somewhat limited output range and might not be suitable for some applications. As the currents through the bipolar transistor devices **12** drop, the noise will also increase, due to added shot noise. However, the simplicity of the implementation makes it a suitable implementation where the temperature range is reasonably small and the required output voltage VR is at a suitable level.

The low noise reference voltage VR can be generated in accordance with FIGS. **1**, **3** and **4**, and an amplifier can be used to amplify this low noise voltage to a desired target value. This can be implemented in a continuous fashion, for example, by using a continuously variable MOS resistor.

The target value also can be obtained by using a programmable gain amplifier and stepping the gain in discrete intervals. An implementation of this is shown in FIG. **5**. In FIG. **5**, the portion of the low noise reference voltage source of FIG. **1** that produces the core voltage is designated **63**, the converter of FIG. **2** is again designated as **40** and the other components of FIG. **2** have the same reference numerals.

In FIG. **5**, IB is the bias current and is supplied from a bandgap voltage reference **60** which provides a bins to the reference source **63** to provide the low noise core voltage, here designated VRP. The bandgap circuit **60** is of a standard well known configuration. The core voltage VRP is applied to the non-inverting (+) input of an amplifier **62** and is amplified and fed back as the reference voltage VR to the respective connected (−) and (+) inputs of the two similar comparators **66**U and **66**D. Bandgap **60** also produces an output voltage VBG which is applied to the non-inverting (+) input of an amplifier **61** whose output is VCM, which is used to reference the common mode of the converter amplifier **42**.

By any conventional means, voltages are generated above (VCM+d) and below (VCM−d) a target voltage VCM. This gives a range of 2d relative to the center reference target VCM. The voltage VCM+d is applied to the non-inverting (+) input of comparator **66**U while voltage VCM−d is applied to the inverting input (−) of comparator **66**D. The comparators **66**U and **66**D each produces a respective output voltage Gup and Gdn, respectively, when its input voltage VCM+d and VCM−d is compared with VR. As described above, VCM may be noisy without degrading differential signal performance. VCM +d and VCM−d are selected as required by system requirements to maintain all voltages within the required operating range. The value for 2d is set sufficiently high so that the switching of the steps of VR will be relatively slow and due only to temperature effects and not to any random noise.

A digital control logic circuit **64** adjusts the gain of amplifier **62** to keep its VR output between VCM−d and VCM+d, where VCM is the common mode voltage of the amplifier **42** in converter **40**. The digital logic circuit **64** has two inputs, one the output voltage Gup of comparator **66**U and the other the output voltage Gdn of comparator **66**D.

Logic circuit **64** includes an up/down counter **64** that is controlled by the voltages Gup and Gdn at the outputs of the two comparators **66**U and **66**D so as to count up or down. A decoder in circuit **64** decodes the counter output and produces a gain control output voltage GC that sets the appropriate gain in amplifier **62**. This is done by conventional circuitry. As illustratively shown, amplifier **62** has a variable feedback resistor **68** between its output and non-inverting input and a variable resistor **69** between its non-inverting input and ground. The output voltage GC of logic circuit **64** controls the values of one or both of resistors **68** and **69**, and thereby the gain of amplifier **62** which sets the reference voltage VR. Amplifier **62** needs to have low noise characteristics, but since speed and input range are limited, this is not a difficult problem.

The trip points of the comparators **66**U and **66**D, which are VCM−d and VCM+d, are set relative to a fixed, non-temperature dependent voltage VCM, as provided by the bandgap. Thus, VR is maintained to the target voltage VCM, which is advantageous for various reasons in circuit design.

We claim:

1. A reference voltage source comprising:

a core voltage generator for producing a core voltage including a transistor having a base, emitter and collector electrode;

the emitter and collector of said transistor being connected between a current supply and a common potential point, and the base being connected to said common potential point, said transistor having an inherent voltage drop between said base and said emitter electrodes which is the core voltage;

a temperature sensitive resistor connected between the base of said transistor and said common potential point to vary the base to emitter voltage drop to compensate the core voltage for temperature changes; and

an amplifier having a first input with said core voltage applied thereto to set the amplifier operating point, a second input for receiving a signal to control the gain of said amplifier, the amplifier output comprising the reference voltage.

2. A reference voltage source as in claim **1**, wherein said core voltage generator comprises a plurality of said transistors connected in series emitter to base between said current supply and said common potential point, the base to emitter voltage drops of said plurality of transistors adding together to form the core voltage to be applied to said amplifier input.

3. A reference voltage source as in claim **2**, wherein said temperature sensitive resistor is connected between the base of at least one of said transistors and said common potential point.

4. A reference voltage source comprising:

a core voltage generator for producing a core voltage including a transistor having base, emitter and collector electrodes;

the emitter and collector of said transistor being connected between a current supply and a common potential point, and the base being connected to said common potential point, said transistor having an inherent voltage drop between said base and said emitter electrodes which is the core voltage;

an operational amplifier having a first input with said core voltage applied thereto to set the amplifier operating point, a second input for receiving a signal to control the gain of said amplifier, the amplifier output comprising the reference voltage, and

a feedback connection comprising a variable impedance between the output of said amplifier and said amplifier second input to provide a signal to control the gain of said amplifier and the magnitude of said reference voltage at the output of said amplifier.

5. A reference voltage source as in claim **4**, further comprising a source of a target voltage, and a circuit for varying said feedback element to vary the gain of said amplifier to set said reference voltage with reference to said target voltage.

6. A reference voltage source as in claim **5**, further comprising a variable impedance feedback element at one of the inputs of said amplifier and wherein said circuit for varying said feedback element varies the value of both of said feedback elements.

7. A reference voltage source as in claim **5**, wherein said circuit for varying comprises a logic circuit including an up/down counter controlled by the difference between said reference voltage and said target voltage to produce an output that varies the value of said variable impedance element.

8. A reference voltage source as in claim **6**, wherein said circuit for varying comprises a logic circuit including an up/down counter controlled by the difference between said reference voltage and said target voltage to produce an output that varies the values of both of said variable impedance elements.

9. A reference voltage source as in claim **1** and further comprising a source of target voltage and a circuit for varying the signal applied to said amplifier second input to vary the gain of said amplifier to set said reference voltage to said target voltage.

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